# HAIL DETERMINATION BY RADAR ANALYSIS[1]

BILLIE J. COOK

Radar Analysis and Development Unit (RADU), District Meteorological Office, U. S. Weather Bureau, Kansas City, Mo.

[Manuscript received February 6, 1957; revised September 4, 1958]

ABSTRACT

Radar reports from 17 radar stations are correlated with hail reports for the 4-month period April through July 1956. The relationship between radar detection of precipitation at long ranges and the occurrence of hail is studied. Fifty percent of all echoes reported at ranges of 135 n. mi. or greater are found to have contained hail. Results of an operational test of the method of analysis are given. Sixty-seven percent of all cases of ¾-inch or larger hail reported in the test area are found to have been identified by the term "Hail Indicated" in hourly radar summaries by the Radar Analysis and Development Unit at the time the hail was occurring.

## 1. INTRODUCTION

Use of the Weather Bureau Search Radar has suggested that echoes observed at long range frequently contain hail. This paper reports (1) results of a comparison of echoes observed at long range and reported occurrences of hail, and (2) results of preliminary operational tests of the suggested relationship by the Weather Bureau's Radar Analysis and Development Unit (RADU) in Kansas City, Mo.

Many factors must be considered when computing the power received at the radar antenna. Since Ligda [1] discusses these factors quite thoroughly they need not be discussed in detail here. Briefly, the return power is directly proportional to the sixth power of the radius of the precipitation particle and inversely proportional to the square of the distance to the target. It seems logical to assume that hailstorms, particularly those producing large hail, should be detected at long ranges since hailstones usually are much larger than the largest raindrops (about 5-mm. diameter). For example, a wet hailstone of 1-inch diameter gives approximately 3,400 times as much power return as a 5-mm. raindrop, all other factors assumed equal. Also, thunderstorms associated with hail are generally of greater vertical and horizontal extent than those associated with rain showers and would be more likely to intersect the radar beam at the long ranges.

The radars that provided the data for this study were WSR–1 and –3 (formerly APS–2) with a power output of approximately 60 kw. Although the radars are basically the same design and power, each had to be considered separately for verification purposes because of the differences in the local installation.

## 2. HAIL DATA

The hail reports used were taken principally from crop damage hail claims reported by over 100 insurance companies. Hail reports from *Climatological Data, National Summary*, and from hourly teletypewriter weather reports were also used. About 95 percent of the hail reports were taken from the 60,000 hail claims. Even with this many reports, it appears that only a small portion of the actual hail was reported. Figure 1 shows the total crop hail claims per degree latitude and longitude for the period April through July 1956. The shaded area of figure 1 is the test area and will be further discussed in the next section. The great majority of the hail claims were from areas where wheat or corn is the principal crop. Few, if any, claims were reported in wheat areas prior to the ripening of the wheat or after the wheat was gathered. Almost no hail reports were received from areas which are principally pasture or forest. The hail reports were plotted for each day with times when known. In most instances the exact times of hail occurrence could not be determined, but routine radar analysis by RADU indicated that in most instances thunderstorm activity occurred only once at the location of a hail report on a given day.

## 3. DATA ANALYSIS

Since the study was concerned with radar observations at long range, a range of 120 n. mi. was arbitrarily selected as the minimum. Thus the area between 120 n. mi. and the maximum range (160 to 210 n. mi. depending on the installation) was the area correlated with the hail reports. This area is referred to as the station sampling area in this paper. Seventeen stations were selected for verification on the basis that at least half of the station sampling area was in the area covered by hail claims. The shaded area of figure 1 is a composite of the 17 station sampling areas. Almost all of the Texas and Oklahoma area is covered by radar with ranges greater than 120 n. mi., while farther north the overlapping is less complete.

The original radar weather observations of the 17 stations were scanned and all echoes at ranges of 120 n. mi. or more were compared with the plotted hail data. These 4,759 echoes were not necessarily the strongest echoes, since the instructions were for the observer to report perimeter points of areas and as many points as necessary

[1] Some of the results of this study were given in a preliminary report entitled "Determination of Hail by Weather Bureau Search Radar" that was presented by the author at the Sixth Weather Radar Conference, Cambridge, Mass., March 1957.

FIGURE 1.—Total hail claims per degree latitude-longitude for the period April through July 1956, with area of radar coverage shaded.

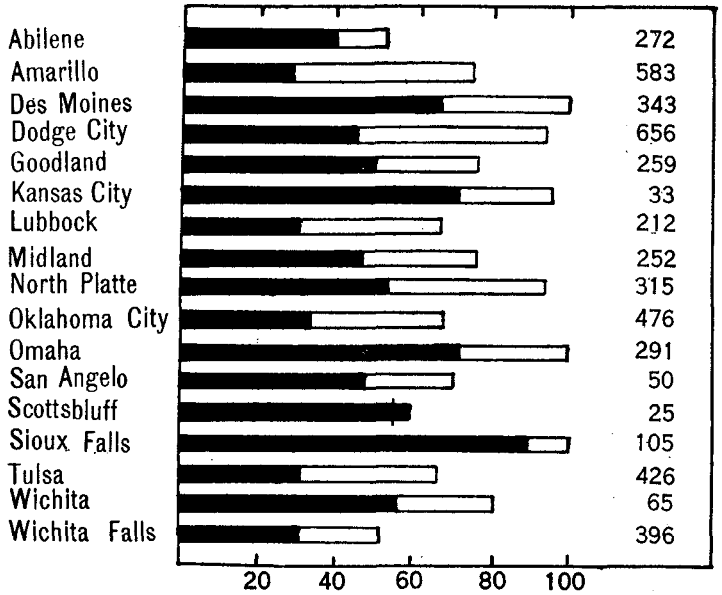


FIGURE 2.—Complete bar (solid+open) is the percentage of the station sampling area which fell within the area of hail claims. Solid part of bar is the percentage of the total echoes (shown by column of numbers on the right) that were verified as containing hail in the test period.

to define a line. If the echo was within 20 n. mi. of a hail report and within 1 hour of a known time of hail (either exact time or approximate time obtained from thunderstorm information), verification was considered positive. A single storm could be reported by more than one radar and for more than 1 hour, thus causing the storm to be verified several times. By the same token, some storms which could not be verified as producing hail were also verified negatively several times.

The radar stations had to be considered separately for verification purposes. For example, one radar detected 656 echoes during the test period while another detected only 25 in the same period. This might be a function of the weather to some extent, but is primarily due to the differences in the local installation and terrain. Furthermore, only a portion of the station sampling area fell in the area of hail claims. The complete bar (solid plus open) in figure 2 shows the percentage of the station sampling area that was within the area of hail claims. Very few hail reports were received outside the hail claim area, although it is possible that as much hail actually fell outside the area as within the area. Since all echoes in the station sampling area were considered in the verification, the verification percentages given by the solid bar in figure 2 should be considered a minimum verification, and of course, more complete hail reports would tend to increase the percentages over those given here. For example, Des Moines, Omaha, and Sioux Falls station sampling areas were completely within the area where hail claims were received and 65, 73, and 88 percent, respectively, of all their echoes were associated with hail; but those stations with only a portion of the station sampling area in the area covered by hail claims had poorer verifications.

Verification varied greatly from month to month due to the fluctuation in the area of hail reports. The U. S. Department of Agriculture *Grain Market Review* shows that in April few crops were at a stage where hail would damage them. Wheat had not begun to head and the Corn Belt was not planted, so relatively few hail claims were filed (fig. 3A). In May, wheat and other small grains were ripening in Texas and Oklahoma and corn was coming up in Iowa and Nebraska (fig. 3B). In June, wheat harvesting was well underway as far north as central Kansas (fig. 3C). In July, the small grains were mostly harvested in Texas and Oklahoma, but were still in the fields and subject to hail damage in Kansas and northward (fig. 3D). Superimposed upon this northward shift of crop damage is the climatological shift of severe weather which is normal during this season.

The dashed lines in figure 3 show that the percent of echoes verified follows the area of hail claims quite closely and a more complete hail report would tend to increase the total verification figures considerably. An interesting note is that almost all radar stations verified hail in over 50 percent of all echoes detected in the station sampling area during one month of the four.

Figure 4 shows that the percentage of verification increased in proportion to range. This of course, is an average for all 17 stations; individual stations might vary considerably from this average, particularly in the shorter ranges. However, the increase in verification from 56 percent at 150 n. mi. to 82 percent at 200 n. mi. suggests

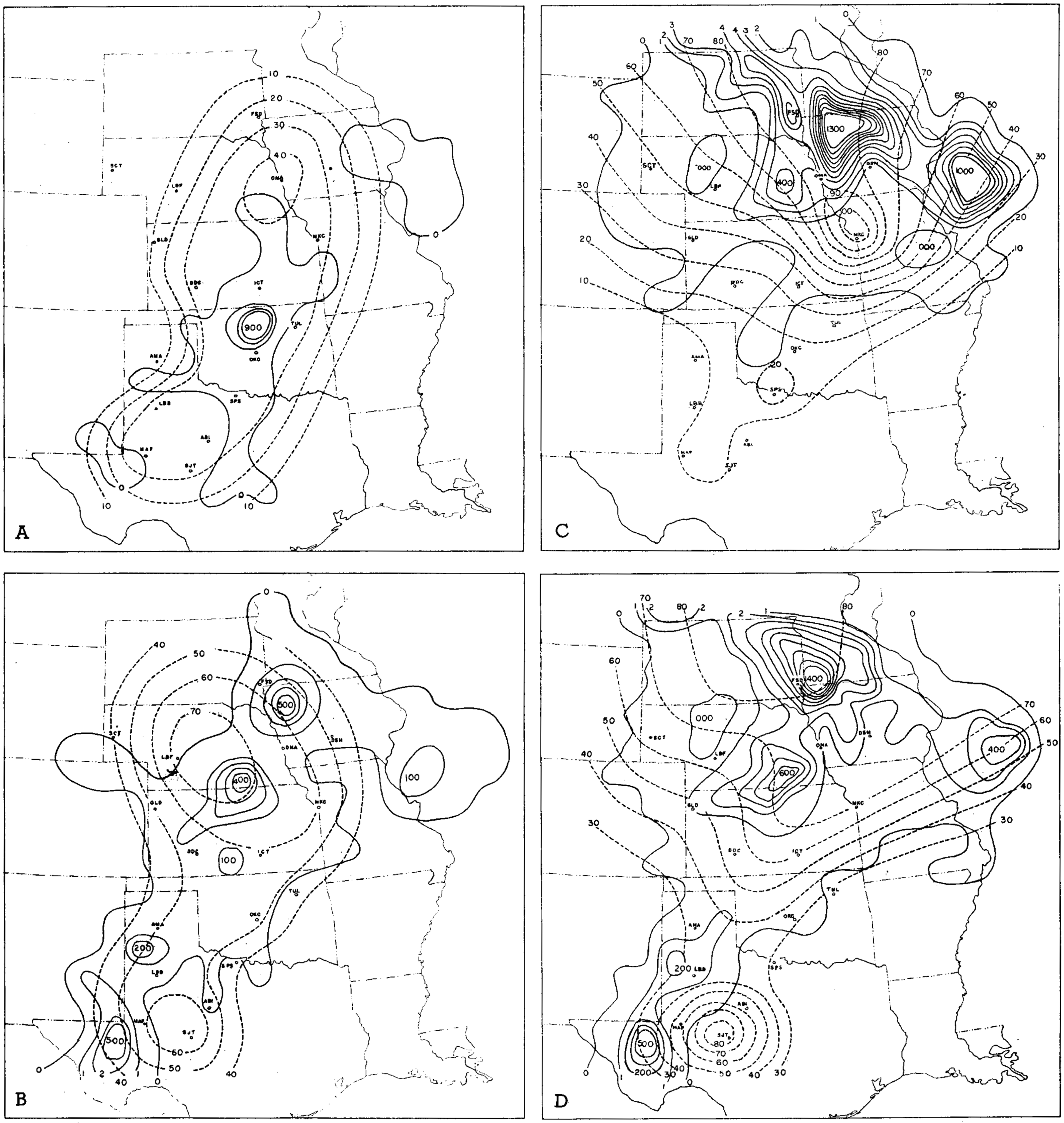


Figure 3.—Total hail claims per degree latitude-longitude and radar verification (percent) for (A) April 1956, (B) May 1956, (C) June 1956, and (D) July 1956.

that hail often accompanies storms detected at these ranges. The number below the curve is the total number of echoes at that range for the test period. The sharp drop in the total number of echoes between 180 and 190 n. mi. is explained by the 180-n. mi. maximum range of many of the radars.

## 4. OPERATIONAL TEST

In a preliminary operational test of the relationship shown by the above results, RADU's hourly radar summary included the term "Hail Indicated" with those echoes meeting certain range criteria during 1956, and

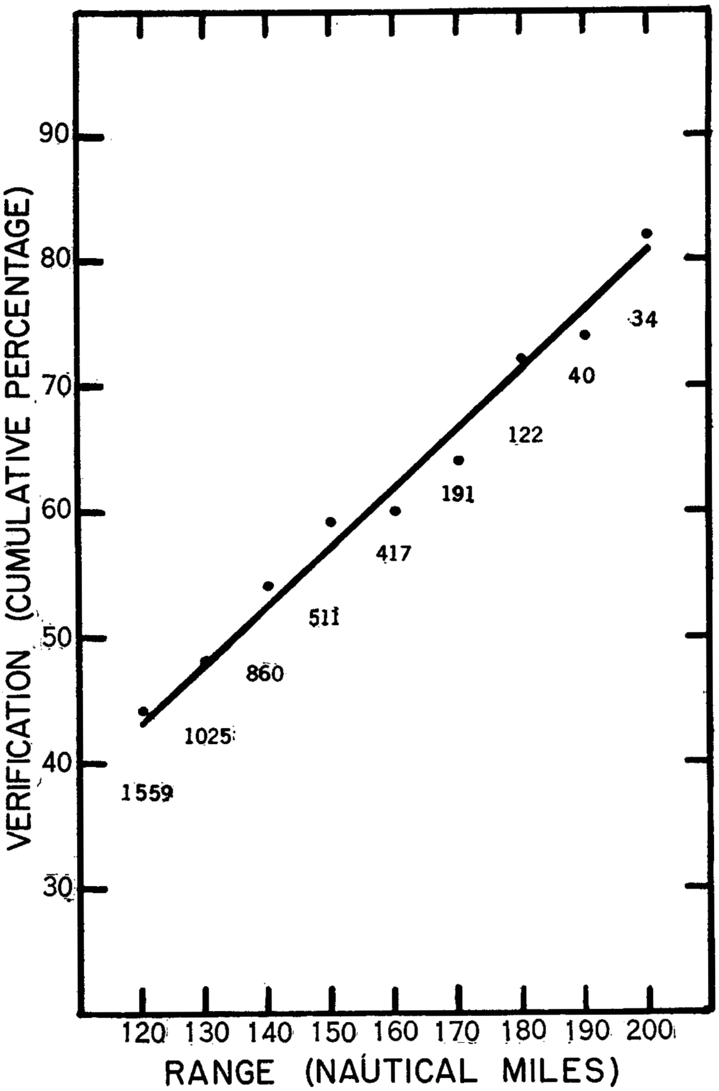


FIGURE 4.—Percentage verification averaged over the 4-month period for all 17 radar stations according to range. The numbers indicate the total number of echoes observed at each range.

March, April, and May, 1957. These criteria were not fixed at any special distance, but all cases were chosen on the basis that a station was reporting an echo at a longer than normal range for that station. It was not practical for an analyst to use the term "Hail Indicated" with every echo observed at 120 n. mi. when the abilities of the individual radars varied as pointed out in section 3. During 1956 the term "Hail Indicated" was used in 182 cases; 56 percent of these were verified as having hail. During March and April 1957 the term was applied to 347 echoes and 35 percent were verified from *Climatological Data* and teletypewriter reports. Hail claims were not available in 1957. This verification seems encouraging when consideration is given to the many factors that limit the amount of hail reported as compared to the actual amount. Sixty-seven percent of all occurrences of ¾-inch or larger hail reported in the test area by the *Climatological Data, National Summary,* for March, April, and May, 1957 were identified with the term "Hail Indicated" by RADU. A few hailstorms that were reported before RADU could analyze the original radar reports were verified negatively in this study.

## 5. CONCLUSION

Verification of hail with precipitation echoes at ranges greater than 120 n. mi. varied from 27 percent at Amarillo to 88 percent at Sioux Falls. Verification changed considerably from month to month with higher percentages moving northward in the summer. Verification increased sharply with range, rising from 44 percent at 120 n. mi. to 82 percent at 200 n. mi. Verification was poor in Texas and Oklahoma in July probably because of the more tropical-type thunderstorms and a lack of hail claims.

These results suggest that an observer should be alert to the probability of hail when any echo is observed near the maximum range of the WSR–1 or WSR–3, regardless of the apparent intensity on the scope. Of course the intensity, and regular forecasting techniques [2, 3] should be used as additional considerations.

In conclusion, if an echo on the WSR–1 and WSR–3-type search radar is observed beyond a specified critical range for that installation and if the radar is operating normally, it is highly probable that the echo contains hail.

## ACKNOWLEDGMENTS

The writer is indebted to Maj. Edwin B. Dickson of the Sferics Section of the Severe Weather Warning Center, U. S. Air Force, Kansas City, Mo., for making the hail claims available, and to the staff members of RADU who gave assistance and advice.

## REFERENCES

1. Myron G. H. Ligda, "Radar Storm Observation," *Compendium of Meteorology,* American Meteorological Society, Boston, 1951, pp. 1265–1282.
2. E. J. Fawbush and R. C. Miller, "A Method for Forecasting Hailstone Size at the Earth's Surface," *Bulletin of the American Meteorological Society,* vol. 34, No. 6, June 1953, pp. 235–244.
3. D. S. Foster and F. C. Bates, "A Hail Size Forecasting Technique," *Bulletin of the American Meteorological Society,* vol. 37, No. 4, Apr. 1956, pp. 135–141.